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Orbital Constraints on HR8799 Planets with 1998 Coronagraphic NICMOS Data

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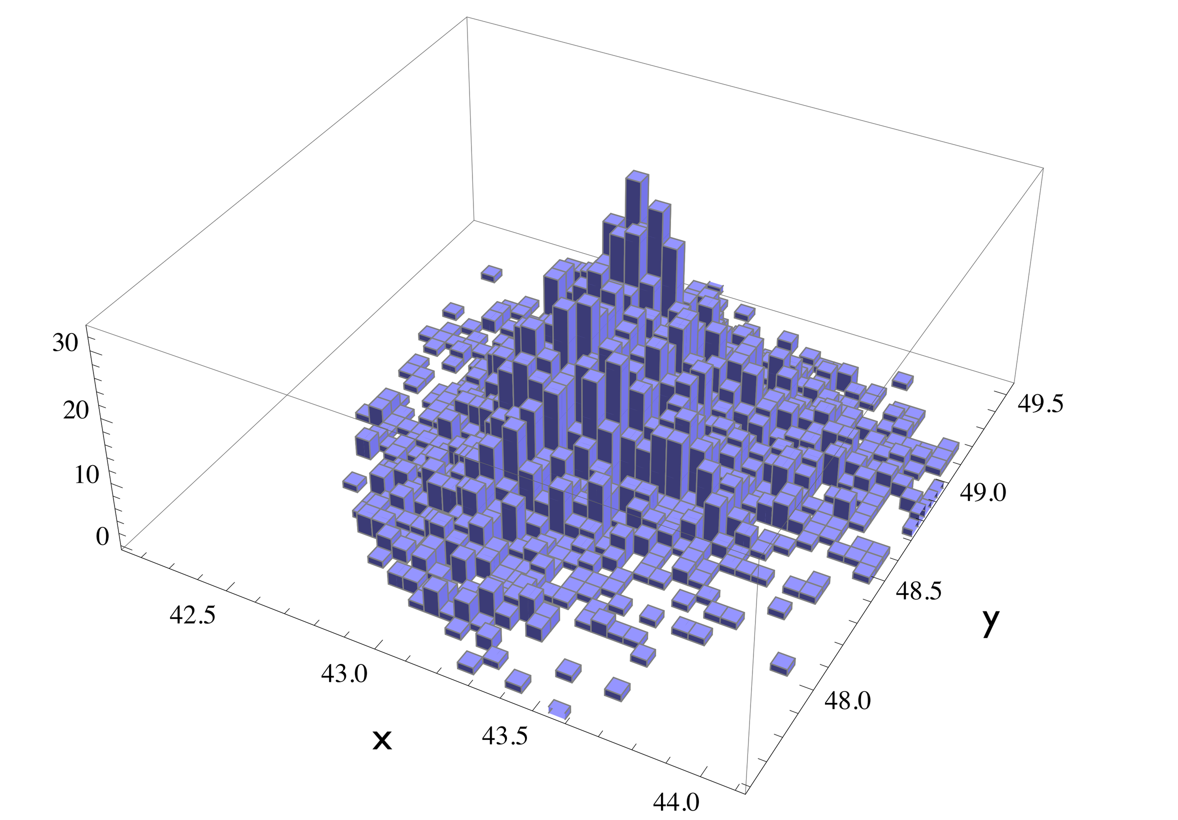
Abstract

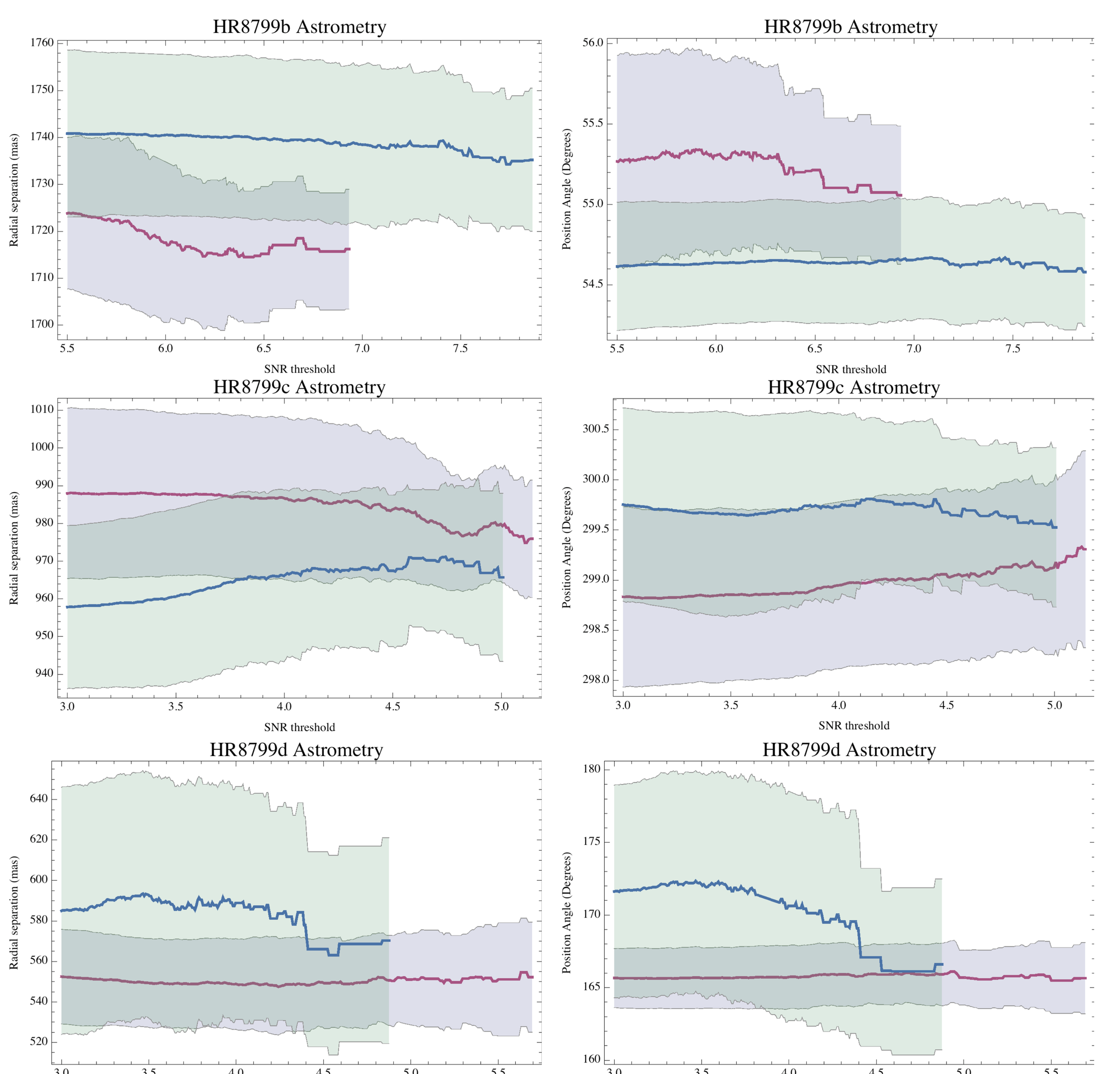
We studied the HST NICMOS coronagraph archival data set of HR8799 from 1998, using the LOCI PSF subtraction algorithm. All dynamical studies have shown that the stability of the system is limited to a few mean motion resonances (MMRs). We select two of the most interesting MMR solutions and assess their compatibility with the additional data points from HST, which provide a ten year baseline with the discovery image from 2008. We improved previous results by Lafrenière et al. (2009) by optimizing the LOCI algorithm and detecting three planets (b, c, and d) in these data. In order to place significant orbital constraints on this planetary system, sub-pixel astrometry is needed since the NICMOS pixel size is relatively large (76 mas). The LOCI subtraction can affect the planet PSF shape, which can create sub-pixel astrometric errors. To minimize these errors, we implemented a series of improvements to the initial algorithm and developed a statistical method for astrometry with LOCI. We studied the statistics of the astrometry as a function of SNR of thousands of LOCI-reduced images, and used simulations with synthetic planets to verify that our LOCI method produces minimal astrometric error. With the new HST data points, we find that both MMR solutions are compatible, but under very strong constraints.

Astrometric Scatter after LOCI



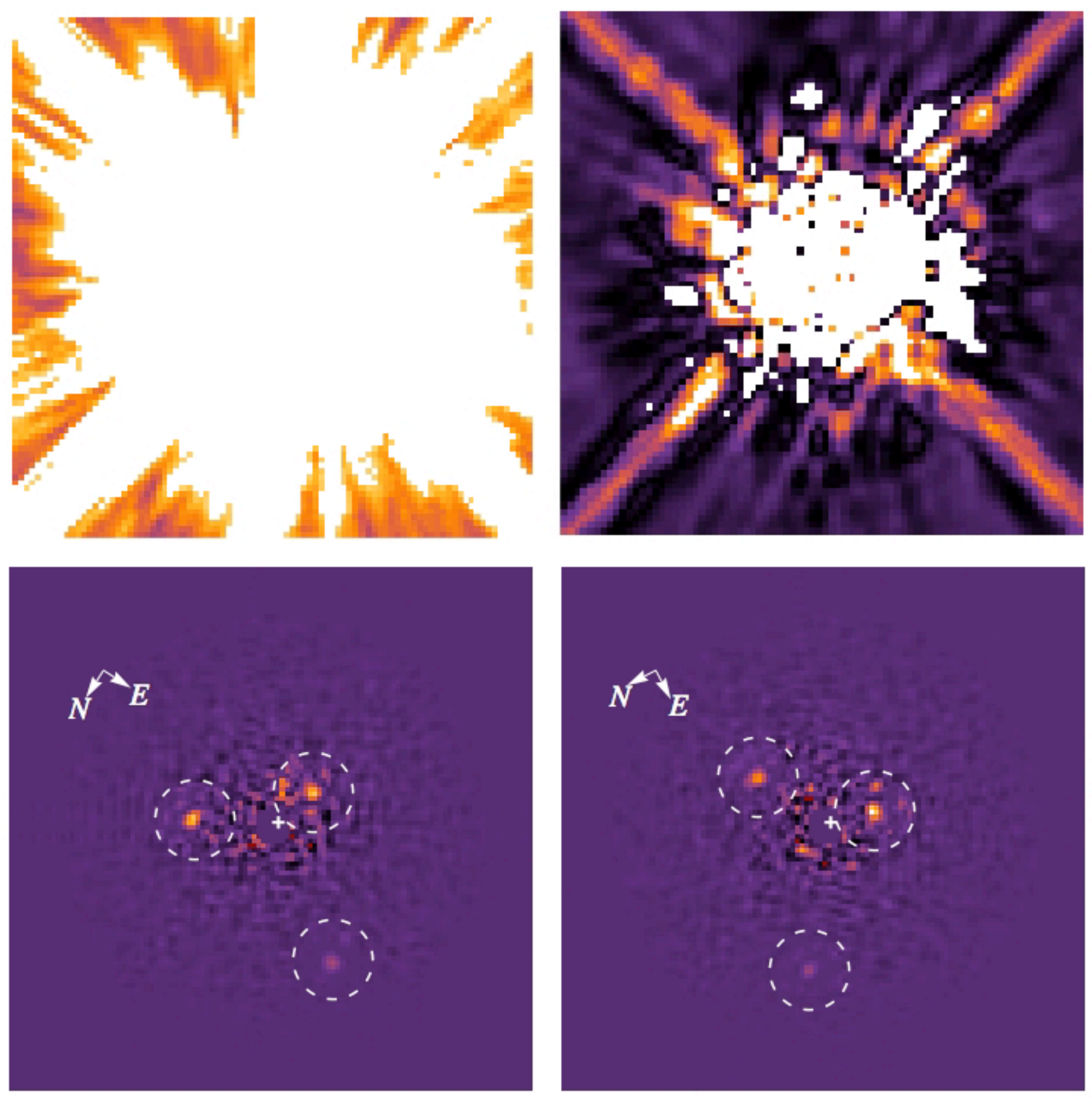
This is a histogram of the astrometric measurements of planet d obtained from a large number of LOCI reduced images (2,000), where each image is generated using a different set of parameters. Instead of optimizing LOCI to produce a single image and then obtain a single astrometric measurement, we take advantage of the speckle diversity introduced by LOCI to develop a statistical approach, and we use the SNR as a proxy to select which LOCI images are included in the statistics. This histogram corresponds to the entire parameter space without any selection. Without any selection criterion the spread is larger than a pixel.

Roll to Roll Astrometric Agreement



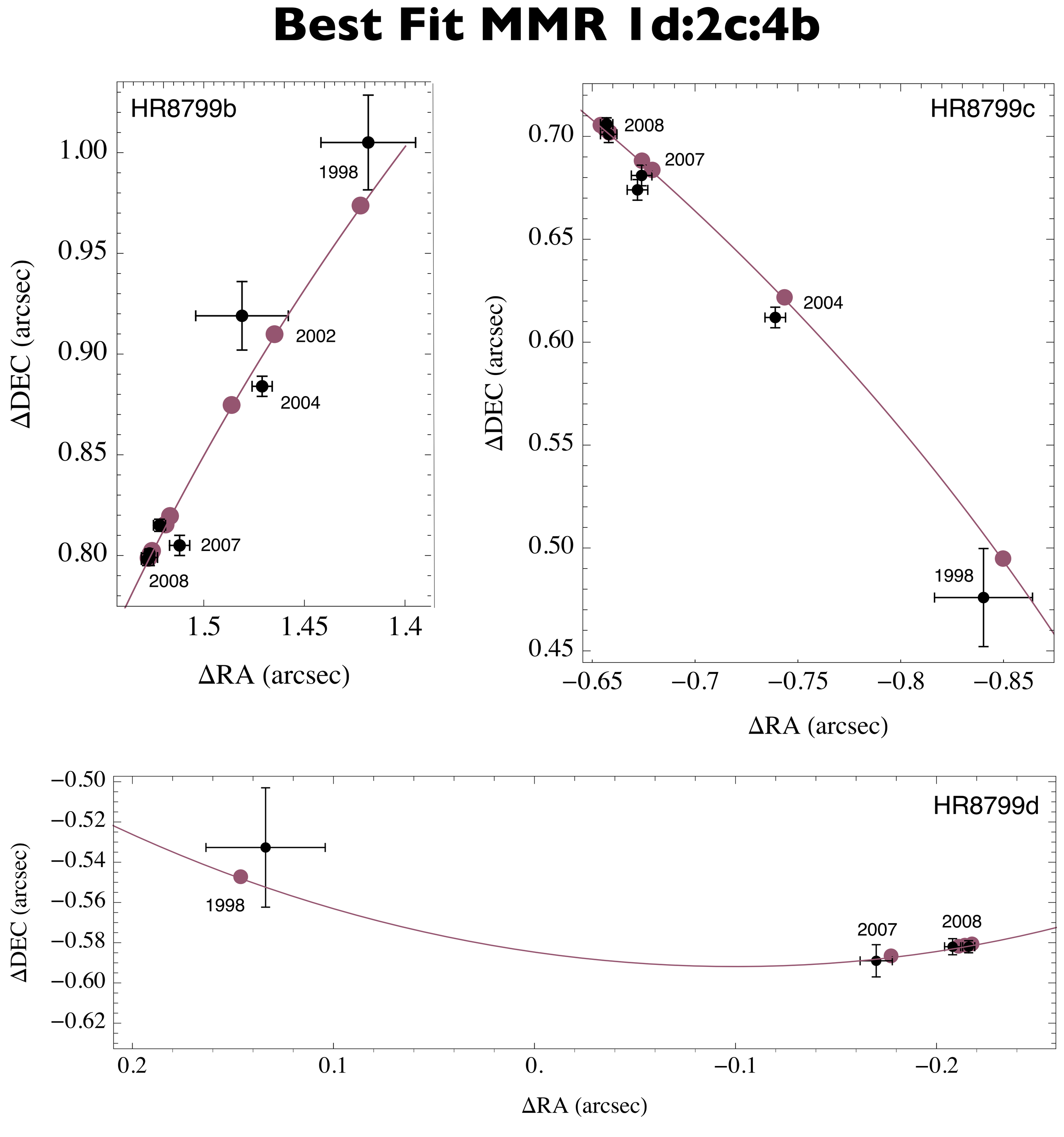
The HR8799 data consists of six images in two roll orientations separated by a roll angle of 29.9 degrees (three images in each orientation). In the figure above, for each planet b, c and d, we show the mean (thick lines) with the 1 sigma error (shading) of the astrometric measurements (radial separation and position angle) in each roll (roll 1 in green, roll 2 in red) for LOCI subtracted images with SNR above a minimum SNR threshold (shown on the x-axis). As the minimum SNR increases, fewer images are included in the statistics. As SNR increases, the astrometric agreement tends to improve from roll to roll. The discrepancies between both rolls are indicative of the residual astrometric biases (speckle noise, star position, systematics) that cannot be calibrated.

HR8799 b, c, and d in 1998 NICMOS data



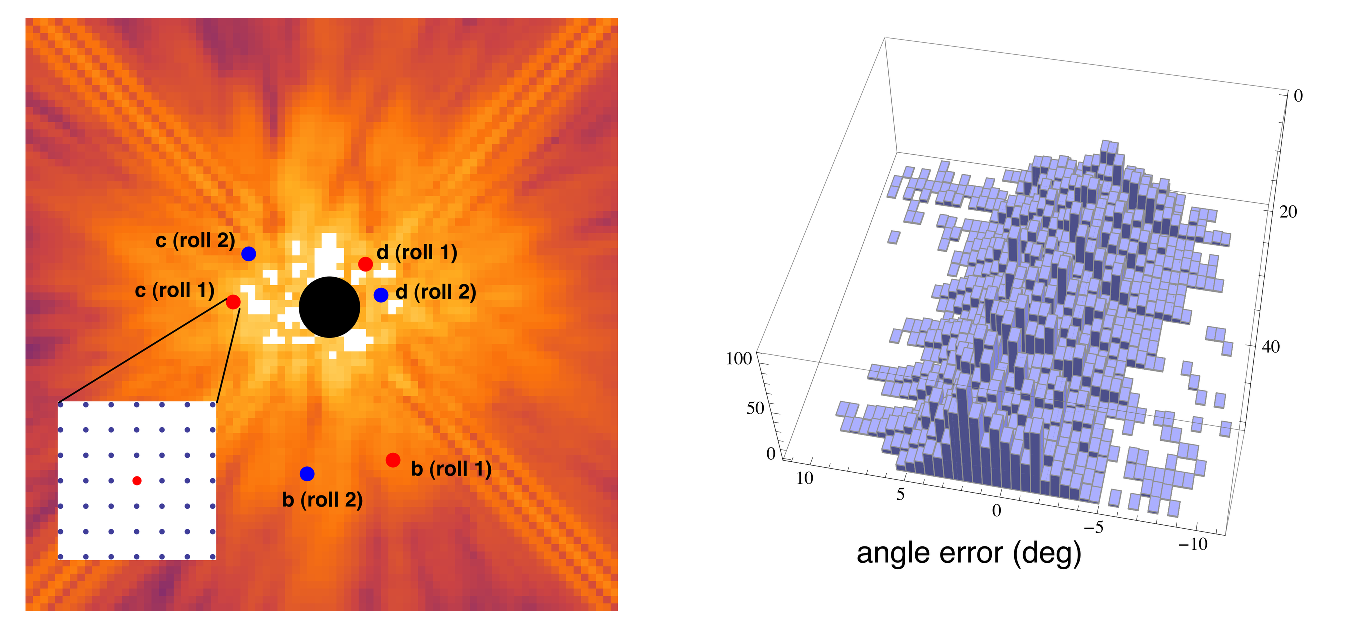
Initial coronagraphic image of HR8799 (top left), Classical PSF subtraction (top right) and final processed images showing the three planets HR8799b, c and d in both rolls in the HST NICMOS data from 1998. We used the median of the best images in the small regions to improve signal to noise in this image. The improvement over the classical PSF subtraction is an order of magnitude in contrast. All four images are displayed on the same scale.

Best Fit MMR 1d:2c:4b



Orbit fits for planets b, c, and d based on the the best fit solution for the 1d:2c:4b mean motion resonance. The p-value of the overall solution is 0.15. The relatively low p-value can be explained by the existence of un-calibrated systematics between different telescopes or observing modes (coronagraphs).

Study of Potential Astrometric Biases



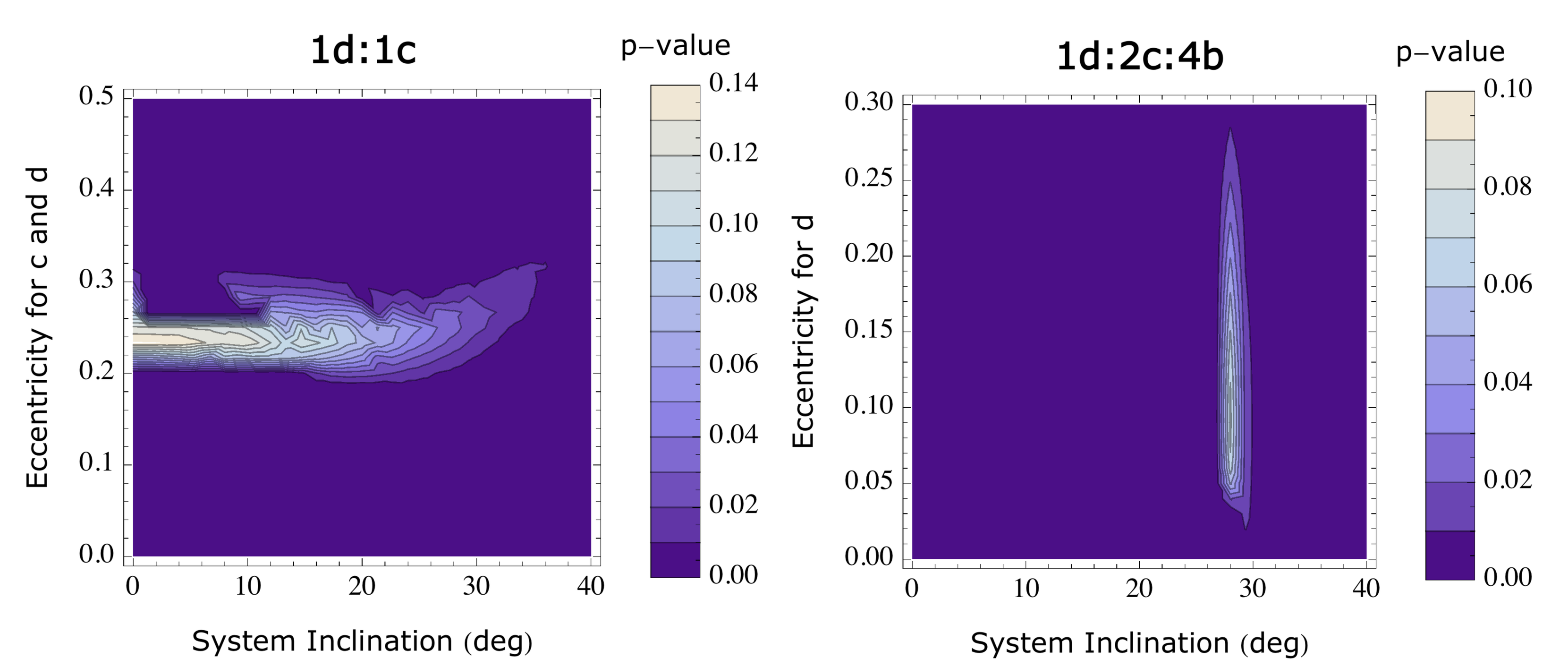
We generate fake planetary systems by injecting fake planets on a 7x7 grid, spanning a single pixel, centered on the measured positions of the real planets (left). For each position on the grid, we explore a LOCI parameter space of ~ 500 parameters, and measure the error between the true position and the measured position for each set of parameters.

The figure on the right shows a histogram of the astrometric errors for the position angle of d-planet at each location in the 7x7 grid. The X-axis gives the measure of the error from the true position. Each increment on the Y-axis corresponds to one of the 49 tested positions for astrometric bias in the 7x7 grid. This study was carried out for all planets in both roll orientations.

We verify that there is no ideal value of the parameter space that guarantees the best astrometry across all positions of the PSF. Our astrometric results are thus based on LOCI images that yield the highest signal to noise ratio.

For all planets residual biases in the simulations are of the order of 0-15 mas. In two instances, planet c in Roll 2 and planet d in Roll 1, we observe significant biases (30-40mas), which can be explained by the presence of diffractions spikes at these locations. We do not use these images in the final astrometric measurement.

Constraints on MMRs



P-values of fitted orbits assuming stable mean motion resonances identified by previous dynamical studies. In the case of the 1d:1c resonance, we assume identical eccentricity for c and d. In the case of the 1d:2c:4b resonance we assume circular orbits except for d. We also assume a mass of 1.47 solar mass for the star (Gray & Kaye 1999). We can rule out most of the parameter space in terms of inclination and eccentricities for these solutions. For the 1:2:4 solution, our best fit corresponds to a small eccentricity for d (0.064) and a very well constrained inclination (~29 deg). Future dynamical studies will be necessary to further study stability using these new data points.

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